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NEW TRENDS IN TECHNOLOGY, AND THEIR APPLICATIONS: DIGITAL DATABASES, GEOGRAPHICAL AND LAND INFORMATION SYSTEMS

A product exchange format for the Defense Mapping Agency's vector products

Paper submitted by the United States of America**

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INTRODUCTION

Demand for machine readable geographic information has exploded during the past few years. The Defense Mapping Agency acknowledged that need and responded with a distributable database structure that would support vector products for its current and future DOD clients. Through a research and development activity, DMA cooperatively developed a standard for the product format with the military map producers of Australia, Canada and the United Kingdom. The design approach included preparation, distribution and evaluation of four prototypes. Seventy-five military, civilian and commercial testing sites participated in this classical textbook approach to design clarification and implementation. In April 1992, DMA released of the Vector Product Format (VPF) United States Military Standard (MIL-STD-600006) which was the culmination of the vector standard development process. All DOD vector product users are asked to comply with that standard when designing systems which use Mapping Charting, and Geodesy (MC&G) data. That VPF standard has also been published as the Vector Relational Format of the Geographic Information Exchange Standard (DIGEST). DIGEST includes a set of standards for data set exchange, developed by the military map producers of eleven NATO nations.

To validate the robust utility of the VPF standard and to provide worldwide users with a large volume of VPF data, DMA designed and sponsored its VPF premiere: the Digital Chart of the World (DCW). DMA released this product for public sale. As a result this general purpose database map is experiencing worldwide distribution for users ranging from military planners to grade school children. Those users share a common interest in geographic information.

DMA has also developed versions of several other vector products for its DOD customers. Vector Map (VMap) will provide vector data with content resolutions equivalent to 1:250,000 and 1:50,000 scale map products. The Digital Nautical Chart (DNC) includes the features and attributes traditionally associated with the varying scales of DMA's harbor and approach charts. For those who must accomplish tactical planning, both the Interim Terrain Data (ITD) and the Tactical Terrain Data (TTD) will be distributed using VPF. ITD and TTD supply mission maneuver information about slope, soil type, known obstacles, vegetation coverage and surface configuration. World Vector Shoreline (WVS), currently a DMA product using a chain-node structure, has also been converted to VPF for distribution.

VPF design allows wide application to a variety of products. The following sections of this presentation will discuss the characteristics of this format and will describe the implementation of the standard for each of the specific products.

VECTOR PRODUCT FORMAT

Models present particular representations or perceptions of reality. To select or to define a model which can be endorsed as a standard requires flexible universality, integral consistency, facile accessibility, and

predictable performance. VPF seeks to satisfy all those design demands. As a generic geographic data model, the vector product format handles any digital geographic data which can be represented using nodes, edges, and faces. The georelational data model provides data organization, defines a five level hierarchy of object abstractions, and supports data quality information. To correctly build the model required particular data structures for which implementation and encapsulation conventions are established at both the table and field levels. At the lowest level of the VPF design, syntax rules are also defined.

Five structural layers constitute the hierarchical architecture of the Vector Product Format. At the lowest level, geometric and cartographic primitives define the spatial aspects. When those primitives are accompanied by thematic information, they create features. The features and primitives build the coverage level. Coverages comprise the libraries. Multiple libraries, in turn, make the database.

The geometric primitives of VPF are nodes, edges, and faces. The nodes represent discrete geographic points or features too small to be resolved as edges or faces. They also link edges together. Edges represent linear features and borders of faces, such as a portion of a road or the edge of a forest. Faces represent area features enclosed by edges such as part of the ocean or a park. The cartographic primitive is text and supports the placement of textual information without being tied to any particular feature. This allows the identification of ill-defined regions such as the Rocky Mountains or the Tasman Sea. These primitives are implemented in five types of primitive tables: Node Tables, Edge Tables, Face Tables, Ring Tables (which link faces to edges), and Text Tables.

Relational modeling defines the features using the primitive and attribute tables. VPF includes three types of feature classes: simple feature classes (points composed of nodes, lines composed of edges, and areas composed of faces), complex feature classes (constructed from simple features), and text feature classes.

Coverages, which are built as a set of the feature classes, interconnect the primitives compliant with the defined topology. A coverage may be considered as analogous to the color composite or separate of the cartographic production process although no design restriction inhibits other separation or integration of feature classes.

This coverage design allows the VPF to support varying levels of topology and varying degrees of integration. VPF recognizes four topological levels. Level 3, known as "full topology," partitions a coverage surface into a set of mutually exclusive and collectively exhaustive faces. Edges meet only at nodes. Level 2, or "planar graph" topology, is a set of edges and nodes where, when projected onto a planar surface, the edges will only meet at nodes. Level 1, the "non-planar graph" topology, contains a set of entity nodes and edges that may meet at nodes. Level 0, called boundary representation or "spaghetti," is a set of entity nodes and edges. Edges contain only coordinates. VPF encourages appropriate feature integration for a particular coverage or layer. When applications do not require carrying relationships among all feature sets, the data can be stored in separate

layers or themes, allowing efficient, tailored exploitation. Conversely, when full topology among all feature sets is required, VPF accommodates full integration, which in implementation could use only one coverage.

Large databases can inhibit effective data management. To alleviate awkward, inelegant database use, VPF allows subdividing a coverage into manageable areas called tiles. VPF provides the mechanism for maintaining geographic features in a logically continuous manner across tile boundaries. The tiling scheme (tile boundaries and size of the tiles) and the handling of the features that lie on tile boundaries and text primitives that cross borders are all defined by the unique product implementing specification. Products which have dense information content can be divided into tiles which cover small geographic areas. Products with sparse information can be divided into tiles which cover larger geographic areas. The existence of the tiled coverage should be nearly invisible to a user; the coverage should appear as a seamless unit.

The primitive, features and coverages already described define the content of the product and the relationships between features. The remaining structural levels of the VPF design, namely libraries and database, are used primarily to facilitate data access. A library is a collection of coverages that share a single coordinate system and resolution or range of resolution, have a common thematic definition, and are constrained within a specified spatial extent. The database is the collection of related libraries and additional tables.

Other features of the VPF, which enhance the utility of geographic information, include the self describing format, the on-line data dictionary, and data quality layer. Self describing format is included in every directory level. Header tables describe the information contained at that level and a description of the level below. Each VPF table has a header describing the table. As a result, software developers can easily prepare utility software which can adapt to any VPF database regardless of the specific product implementation. The on-line dictionary enables feature and attribute definition to be included in the product. This design will avoid much user confusion. The VPF utilizes "Value Description Tables" that specify and describe the coded feature attributes used in each coverage. In addition, users can employ this capability when they add supplementary data to the database. As an example, crude oil flow, as a database element, could be enhanced by adding the rate of flow under differing environmental conditions studied by a variety of different users. Any coverage can be supplemented by value-adding users who were unknown to the distributor of the database product. Yet those users participate interoperably and accurately. VPF also allows any product to incorporate data quality information at both the library and the coverage levels. Such information has exceptional value to geographic analysis by aiding informed judgments based upon realistic assessments.

VPF PRODUCTS

Although the developmental objective was to establish a suite of standards and to enhance the utility of digital spatial information in vector format, the effort would have been barren without a wealth of data and a user-friendly software interface. No less ambitious than the design of the format standard was the development of the first product implementation, the Digital Chart of

the World (DCW). In addition, the Defense Mapping Agency has aggressively pursued prototyping new vector products which currently are in the initial stages of production. To assist users, applications software for simple database query accompanies VPF products.

The Digital Chart of the World (DCW)

The DCW is a general purpose digital global database designed to support Geographic Information System (GIS) applications. The international mapping community, represented by the International Cartographic Association and the International Geographical Union, has documented the need for such a database since the early 1980s. Users, as varied as environmentalists, military mission planners, archaeologists, sociologists, or the intelligence community, need this information. DCW's development does not support any individual specialized operation. Therefore, it was not optimized for a single application, but rather was organized to be especially convenient for military, scientific, and educational GIS exploitation.

The completed product architecture is one database with five libraries comprised of multiple coverages. Seventeen hundred megabytes of information are distributed on 4 CD-ROM discs. The DCW is the largest global spatial database in vector format. One disc alone contains 40,000 files.

Each disc contains 2 libraries. An overview library, the Browse Map, has been thinned to a resolution representing the level of information that might be found on a 131,000,000 scale paper product. This Browse Map is duplicated on each disc to offer access to selected global information. The other library on each disc covers approximately a quarter of the world at a resolution equivalent to a 1:1,000,000 scale chart. Disc 1 covers North America; disc 2 covers Europe and North Asia; disc 3 covers South America, Africa, and Antarctica; and, disc 4 covers South Asia and Australia.

Two-hundred and seventy Operational Navigation Charts, augmented by 6 Jet Navigation Charts over Antarctica, were digitized to provide worldwide coverage. Other input sources were DMA's Digital Aeronautical Flight Information File (DAFIF) for airfield information, the Advanced Very High Resolution Radiometer (AVHRR) imagery for vegetation classification in the continental United States, and Joint Operations Graphics (JOGs) and Tactical Pilotage Charts (TPCs) for transportation connectors through selected populated place polygons.

The four area-specific libraries of the DCW have 17 coverages and a place names index. Those coverages and sample features are:

1. Aeronautical (Civil and Military Airports)
2. Culture Landmarks (Structures, Tank Farms, Silos)
3. Data Quality (Chart Lineage, Accuracies)
4. Drainage (Streams, Rivers, Lakes, Inland Water)
5. Drainage Supplemental (Small Lakes)
6. Hypsography (Contours, Zones, Spot Height)
7. Hypsography Supplemental (Partial Contours)
8. Land Cover (Cultivation, Wetlands, Distortions)
9. Ocean Features (Reefs, Exposed Wrecks)
10. Physiography (Levees, Outcrops, Faults, Cliffs)

11. Political/Oceans (Oceans, Shoreline, Countries)
12. Populated Places (Built-up Areas, Towns, Villages)
13. Railroads (Single Track, Multi-Track, Light Rail)
14. Roads (Dual Lanes, Primary, Paths)
15. Transportation Structures (Bridges, Tunnels, Fords)
16. Utilities (Power Lines, Pipelines, Telephone Lines)
17. Vegetation (Range land, Forest)

To facilitate data management, the DCW primitives have been geographically subdivided into 5° x 5° tiles. The primitives, stored in small files, are connected through the use of keys to the feature/attribute tables, stored in a single large file, consistent with standard relational design rules by adding a column for each feature class onto the primitive files.

The DCW is available to GIS users throughout the world. In the United States, Department of Defense (DOD) customers can request the product through DMA's Combat Support Center and non-DOD customers can purchase a copy through the U.S. Geological Survey (USGS). The co-developers, the military mapping organizations of Australia, Canada, and the United Kingdom, also distribute the DCW. This product design has also been accepted by the DIGEST countries as the "dataset" called Background Data Display (BDD), Level 0.

Future editions of the DCW will be redesigned to be compatible with DMA's Vector Map products described below. The DCW will become Vector Map Level 0. The information content will remain the same, however, the thematic coverages will be condensed to the ten listed under VMap. The database will be updated, boundary and country name changes and error corrections will be incorporated into the new product.

Vector Map (VMap)

The goal of a global database at a denser resolution than DCW is yet in the developmental stages. Over five years ago, DMA envisioned interoperability based upon a robust suite of exchange standards. The DCW was a desirable first step for vector information because the cartographic source base maps existed on a worldwide basis. Now, in the early nineties, however, the agency has acknowledged the timeliness of expanding the early visions by building an extensive vector database equivalent to a 1:250,000 scale chart - VMap Level 1. This product will be supplemented by higher resolution product, equivalent to the 1:50,000 scale chart - VMap Level 2. The two resolutions, which will be captured as two VPF databases, need not be coextensive. Only selected areas of interest will feature both the medium and higher resolution information.

As DMA initiates production of VMap, the JOG (1:250,000 Joint Operations Graphic) and the TLM (1:50-100,000 Topographic Line Map) information will be digitized from the paper product, vectorized and attributed in a process similar to that used for the DCW. Line and area features will be collected respectively as continuous and closed features, connecting the breaks in contours or other linear features which allow for deconflicted text placement on paper but which are not necessary for digital representation. This compensation enables the georelational topology inherent in the VPF design. All VMap products incorporate the DIGEST Feature Attribute Coding Catalog (FACC) coding schema for feature and attribute definitions and encoding.

To facilitate the anticipated integrated use of the medium and higher resolution data, the databases will reflect consistent thematic coverage divisions. Certainly, the higher resolution libraries will express richer levels of feature content and be more heavily attributed. All VMap products will organize data into the following coverages, listed along with examples of feature content:

1. Boundary (International, Fences, Cease Fire)
2. Data Quality (Source, Dates , Accuracy, Voids)
3. Elevation (Spot Heights, Contours, Depths)
4. Hydrography (Rivers, Streams, Rapids, Dams)
5. Industry (Mines, Quarries, Tanks, Grain Elevators)
6. Physiography (Formations, Caves, Volcanoes)
7. Populated Places (Buildings, Parks, Ruins, Towns)
8. Transportation (Roads, Railroads, Airports, Bridges)
9. Utilities (Power Plants, Pipe Lines, Utility Lines)
10. Vegetation (Forest, Swamp, Grasslands)

The prototype design process for VMap has been completed. A draft product specification for VMap Level 1 has been distributed to DOD customers for final review. Final comments will be incorporated and the document will become a United States Military-Specification (MIL-V-89033) by late spring 1994. VMap Level 2 is currently undergoing an iterative prototype development process.

Several co-producing nations will help populate the medium and higher resolution libraries and databases. The co-producers have supported the review of the draft product specifications and have shared in the evaluation of the prototype products. The VMap design has been adopted by the international DIGEST community as a data set model for the Background Data Display, Level 1 and Level 2.

Digital Nautical Chart (DNC)

Another new DMA product is the Digital Nautical Chart (DNC). The DNC database is comprised of varying resolution libraries over a specified operational area. Multiple libraries, rather than the multiple databases of VMap, are used for resolution differences. DMA's customer-sensitive implementation of VPF emphasizes the flexibility of database-library definitions.

A DNC Sampler has been produced on CD-ROM to show the multi-library concept typical of the product. It includes databases covering the Seattle, Washington and the Norfolk, Virginia areas. Users can switch from library to library as more or less detail is required. For an example, the Norfolk area database contains a General Library which covers the United States mid-Atlantic coastal area at a resolution of data comparable to a 1:1.2 million scale chart, and a Coastal Library, which includes a resolution of data comparable to a 1:300,000 scale coastal chart, covering the coast from Maryland to North Carolina. These could provide information as a ship operates off the east coast of the United States. As a navigator nears Norfolk, more detailed information is needed and that user switches to the Approach Library for the Chesapeake Bay with a data resolution comparable to a 1:75,000 scale approach chart. Closer to port the pilot will need even more

finely detailed information which will be found in the Harbor Library, comparable to the resolution of a 1:20,000 scale harbor chart.

Although these scales are quite specific, reflecting the specific charts used, the product specification allows for a range of paper chart scales for each resolution library, which overlap slightly: General and Browse for small scale, large area coverage; coastal from 1:75,000 to 1:500,000; approach from 1:25,000 to 1: 100,000; harbor from 1:10,000 to 1:50,000.

Like the databases of VMap, DNC's multiple libraries reflect common themes to ease the transition from one resolution to another. The following documents the coverages and sample of feature content:

1. Avoidance Limits (Mines, Prohibited, Restricted)
2. Caution Limits (Anchorage, Maritime Limits)
3. Cultural Landmarks (Towers, Railroads, Roads)
4. Data Quality (Chart Lineage, Accuracy)
5. Earth Cover (Coastal Shoreline, Named Location)
6. Environment (Tide Gauge, Magnetic Disturbance)
7. General Information Limits (Customs, Radar)
8. Hydrography (Depth Curve, Sounding, Bottom)
9. Inland Waterways (Lakes, Rivers/Streams, Dams)
10. Land Cover (Glaciers, Dunes, Orchard, Swamp)
11. Aids to Navigation (Buoy, Beacons, Lights)
12. Navigation Limits (Dredged Channel, Harbor)
13. Obstructions (Wrecks, Reefs, Rocks, Kelp)
14. Port Facilities (Breakwater, Dry-dock, Jetty, Pier)
15. Relief (Contours, Spot Elevations)

DNC production is now underway at DMA. When complete, the product should provide near worldwide coverage on approximately 30 CD-ROMs. In the near future, the DNC products will be used to assist on-board navigation. They represent a major step helping the Navy reach its goal of a paperless bridge. DMA must also work with the Navy and Coast Guard to define a timely maintenance approach for maritime safety using this new format and the CD-ROM media. Technical discussions have been initiated on feasible solutions to such a thorny problem.

World Vector Shoreline (WVS)

Today DMA distributes a fairly non-complex digital vector product, at a nominal 1:250,000 scale-like resolution, which includes international boundaries, country names and shorelines derived from vector processing the Digital Landmass Blanking data. World Vector Shoreline (WVS), structured as chain node vectors and formatted as ASCII code, offered itself as a ready opportunity to test the interpretability of the VPF standard documentation by an independent activity. DMA tasked the Navy laboratory in San Diego, NRaD, to convert WVS to VPF, initially with only Level 0 topology and, later, with Level 3 topology. NRaD's contractor has successfully accomplished these tasks, relying upon VPF developers for clarification, and, in the process, shook out some documentation weaknesses. DMA is now in the process of producing the WVS as a complete global product providing shoreline data at multiple resolutions ranging 1:250,000 and smaller.

Interim Terrain Data (ITD)

DMA is converting another existing vector product to VPF, using its internal technical expertise. The Interim Terrain Data, compiled to support extensive Army requirements for detailed topographic information, has been distributed with a six-file, chain-node structure in DMA's Standard Linear Format (SLF). ITD's contiguous datasets cover specified geographic footprints. Attributed and unsymbolized features fall into six segregated files which will be used as the following coverages in the one VPF Library for this database:

1. Surface Configuration (Slope, Open Water)
2. Vegetation (Forested, Swamp, Non-Forested)
3. Surface Material (Soil)
4. Surface Drainage (Rivers/Streams, Banks/ Bottoms)
5. Transportation (Roads, Railroads, Bridges)
6. Obstacles (Escarpments, Walls, Fences, Pipelines)

Attributes carry highly detailed information to assist automated terrain analysis tasks such as terrain visualization, route and site selection, mobility and countermobility planning, communication planning, navigation, and fire support planning and execution. A preliminary product specification and prototype have been developed.

Tactical Terrain Data (TTD)

Like ITD, the Tactical Terrain Data (TTD) will be a terrain analysis database but will included higher resolution information and will be exploited in a value-added environment. TTD is not among DMA's current products. Once the full operational capability of DMA's modernized Digital Production System (DPS) is realized, however, this product will replace the ITD. Unlike the 2-D SLF format of ITD, TTD will contain three dimensional feature data in the VPF structure and format. A prototype is under development using a multi-database approach. TTD will use data from VMap, DNC, and a redesign of the coverage themes of ITD named the Digital Terrain Analysis (DTA) data set. This design approach will allow the analyst maximum flexibility in GIS analysis.

VPFView Software

One of the objectives of the DCW project was to provide reviewers and casual users of the product with an effective software tool to access, display, and evaluate data content. VPFView software has been developed to display any data product which conforms to VPF. As new prototypes are developed, VPFView is furnished to provide potential users a means to analyze, test, and display the products, allowing them to provide feed back to insure the product fits their needs. VPFView is available in both the MS DOS and UNIX environment.

VPFView options permit browsing the metadata tables, displaying data on a monitor screen and using several graphics functions which include zooming, projections, grids, and distance measurement. A user can examine the on-line data dictionary, modify default symbolization, produce text reports, and save bit maps or fully interoperable datasets to the hard disk. With appropriate hardware, users can also output graphics to printers.

VPFView is not a Geographic Information System. It has no capability to prepare sophisticated queries which associate one layer of data with another, one range of value with other geographic attribution. But VPFView is a model for more advanced applications and allows other commercial, government or academic endeavors to readily capture the format descriptions from the code which is distributed with the product.

SUMMARY

DMA has committed its production capability to a new generation of products, information which will be readily assimilated into data-hungry computers of the future. Those computers will demand extensive spatial data which is richly attributed and has high resolution. The dynamic information systems of the future will enhance military, scientific, social, commercial and environmental policy making only if well-motivated efforts provide quality, intelligent, easily-accessed data. The VPF standard has been designed to support flexibility of product implementation, to deliver accurate geographic information and to identify a reliable and expected product-exchange structure and format.